# MICROTOPOGRAPHIC INSPECTION OF THERMOPLASTIC RUBBER SHOE'S SOLE: THE INFLUENCE OF SURFACE ROUGHNESS ON SOLE TO LEATHER GLUING

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## INTRODUCTION

In Portugal quality shoe's industry has a major economical importance. The strength and quality of the gluing of the sole to leather are of major importance in the process of making a high quality shoe. This pasting process is standardized for different kinds of sole/leather combinations. However even if proceeding carefully, strictly by the rules, problems due happen and specially as new kinds of sole's materials and leather' types are introduced in the production lines. A careful physical characterization of the gluing process as well as all items intervening is again necessary.

In order to increase the leather's adherence to the thermoplastic sole a chemical product is applied on the sole surface before applying the glue. The chemical interaction produces a change in the sole' structure. The topographic structure of the sole's surface will also change.

We wanted to figure out the possible influence of the roughness of the surface of thermoplastic rubber soles on the shoes' gluing quality. The roughness and other microtopography characterization parameters was measured and calculated for different sample before and after the application of the chemical product. The gluing strength is also measured for correlation. Apart from the standardized conditions we decide also to vary the amount of chemical used and the pressure placed on the brush. Different values and regimes of the surface's roughness were expect.

Those materials have not enough self-consistency to use a stylus profilometer for roughness evaluation. Thus we decided to use our own developed microtopographer, the

MICROTOP.03.MFC, based on the active optical triangulation method, to perform the inspection of the surfaces. Most of the samples are slightly translucent and of course this poses some problems to the inspection process. However our strategy of detection of the scanning bright spot is able to overcome the light diffusion underneath the sample' surface, allowing accurate and reliable measures. A Rodenstock RM100 topographer was also used for confirmation and its results were found to be consistent with the above ones.

Concluded was that when proceeding accordingly with the standard of the chemical's application, the mean roughness of the surface does not increase significantly. However the roughness regime was different with an increase of the weight of the surface's high frequencies. It was also observed that increasing the surfaces' roughness (by the increase of brush's pressure for instance) do not allow the best pasting depending on the glue and leather used.

## A BRIEF DESCRIPTION OF OUR DEPTH SENSING METHOD

Over the last decade an automated system of 3D topographical inspection of rough surfaces[1-4] was developed by the first author at the Laboratory of Microtopography of the Physics Department of the University of Minho[9]. The system, briefly described below, is based on an active optical triangulation method with oblique incidence and normal observation, and mechanical sample's scanning.

The surface to be inspected is scanned by an oblique light beam (Figure 1.). The incident light is collimated and focused. A small, diffraction limited, bright spot is thus projected onto the sample. The bright spot is perpendicularly imaged onto an electronic photo-sensitive detection system in order to assess it's lateral position. The area of the surface to be inspected is scanned point by point by the "sensor's tip" (the light beam focused onto the surface).

The highest system's robustness was sought. Also a high lateral positioning resolution and accuracy should be achieved. Thus we decided to keep both the incidence and observation arms of the sensor fixed. In order to perform the sample's scanning it will be moved by means of a precision XY displacement table driven by precision step motors. At each scanning point the lateral spot's position is obtained and registered. The horizontal spot's shift between scan positions is directly related with the height differences between those surface inspected points.

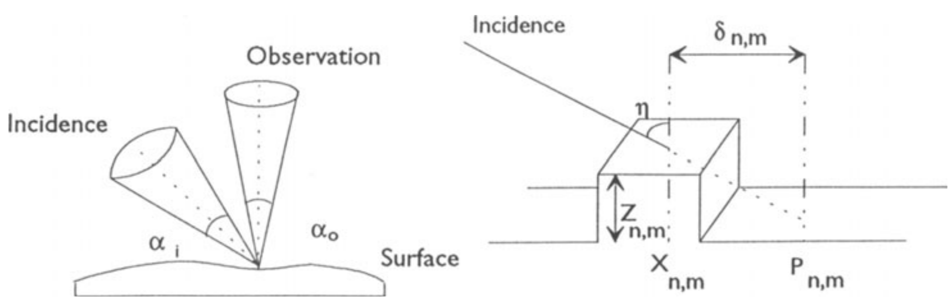


Figure 1. The surface's relief inspection system we implemented is based on the geometry sketched above. The intersection of an oblique light beam with an opaque surface creates on it a bright spot whose lateral position depends on the surface height.

From Figure 1. and the above considerations is easy to see that the set of 3D co-ordinates obtained by the system is:

$$X_{n,m} = n\Delta - \delta_{n,m} ;$$

$$Y_{n,m} = m\Phi ;$$

$$Z_{n,m} = (\delta_{n,m}/M) \cot \eta ,$$

where $\eta$ is the incidence angle, $\Delta$ the sweep increment in the direction of the plane of incidence (X) and $\Phi$ in the perpendicular one, M the magnification of the observation system placed above, perpendicularly, to the surface, and $\delta_{n,m}$ the spot shift (on the X direction), regarding a reference position $P_{n,m}$, at the scan position ($X_n$,$Y_m$).

The tridimensional reproduction of surface's relief structure can then be performed in different ways and statistical surface characterization parameters are computed.

BRIEF OVERVIEW OF THE MICROTOP.03.MFC SYSTEM'S CONFIGURATION.

The MICROTOP.03.MFC sketched on figure 2. is a robust and versatile system specially designed to accurately perform the microtopographic inspection of the rough surface of small samples. It allows the inspection of a large variety of surfaces with resolutions that can be driven down to the submicron level with dynamic ranges up to 1:5000. It was used in different inspection tasks such as: thickness measures and relief mapping of thin sputtered cooper, tin dioxide and silver films, polyethylene films, several kinds of fabrics (as far as I know for the first time in a non invasive way); and, roughness measure and topographic inspection of polyethylene molds, graphite samples, wax casts...

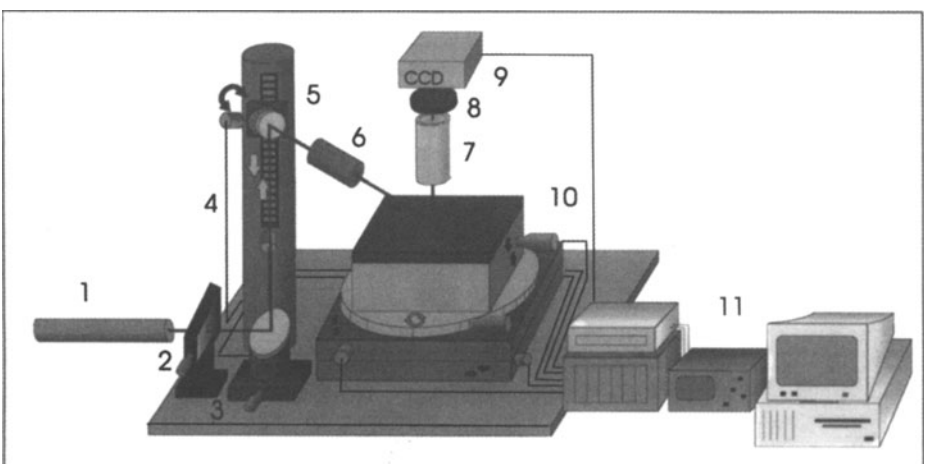


Figure 2. The MICROTOP.03.MFC: 1. Light source; 2: Vibration isolation stand; 3. Neutral density filter; 4. Beam steering system; 5. Incidence angle control motorized system; 6. Incidence optics; 7. Observation optics; 8. Interference filter; 9. Line scan camera; 10. Sample support and motorized positioning system; 11. Data acquisition and control system.

An oblique light beam (two HeNe lasers at 632.8 nm and 534 nm, and one Xenon white light source are available and can be easily interchanged) shines on the surface placed on a scanning assembly. A rotation stage placed on a vertical stand is used to mount the laser allowing easy change of the incidence angle. In order to guide the incident beam onto the sample an incidence optical system was assembled. It comprises a neutral density filter for optical power control and a lens system that cleans and focus the beam onto a diffraction limited spot on the surface. The sample positioning set-up is formed by a X,Y precision linear stage moved by two step motors allowing the sampling of points on a rectangular array separated by distances down to 1.25 μm. In order to resolve shaded areas and mutual reflections, a high precision rotational stage is used allowing easy change to opposite light incidence. It can also be used to help the sample positioning. In order to keep the incidence and reception optical systems in accurate focus over the sample, the X,Y scanning system rests on a vertical movement precision stage endowed of computer controlled motion provided by a reliable accurate DC encoder with high positioning repeatability and resolution. The observation optical system is formed by a microscope objective chosen according to the characteristics of the surface's relief. A complex optical system offering large working distance and high depth of focus, the so called macroscope (Infinity's HDF macroscope) is also available. Small objects or surfaces presenting large height differences, up to several millimeters, can be easily inspected. They will be used to image the light spot onto the opto-electronic photo-sensitive detection system(s). A CCD linescan camera (Fairchild CCD143) is commonly used. However a PSD (position sensitive device) from Sitek can be used instead. Also, a beam spliter (not shown in Figure 2.) allow the simultaneous use of both the CCD and the PSD thus enabling a direct comparison of the system's performance when employing each of them[4]. The depth resolution and the dynamic range with the same system's configuration is smaller when using our PSD. Although data acquisition time with the PSD is higher, a larger range of surfaces can be inspected (even when where the spot's "brightness" is very shallow) with the available illumination power. The use of the CCD array have the extra advantage confocality due to the small size of the photo-elements [7,8].A personal microcomputer acquires the data and takes control of the whole inspection process and result's presentation.

The calibration procedure[1,2] is a major issue in this technique as it might take care of some misalignment or aberration problems. It can be efficaciously done simply by moving vertically a reference sample while registering the lateral spot's position.

## EVALUATION OF THE DEPENDENCE OF THE PASTING QUALITY ON THE ROUGHNESS OF THERMOPLASTIC RUBBER SOLES

In order to improve the strength of the thermoplastic rubber sole to leather gluing, a liquid product (halogenant) is applied on the sole's surface with the help of a brush. Although not ISO certified this is a standard procedure within quality shoe's making industries. The mechanism by which this procedure improves the pasting strength is not yet fully understood. Some peoples suggested that the product induces an increase of the sole's surface roughness thus increasing the pasting strength. We investigate that possibility and concluded that this is not true. The interaction should be mainly chemical. Several samples of different types of thermoplastic rubber sole have been inspected topographically. Our microtopographer, MICROTOP.03.MFC, was used as well as a Rodenstock RM 100. For each sole different areas where identified and analyzed. By simple visual observation we could foresee the existence of important differences on the relief structures even on the same rubber piece.

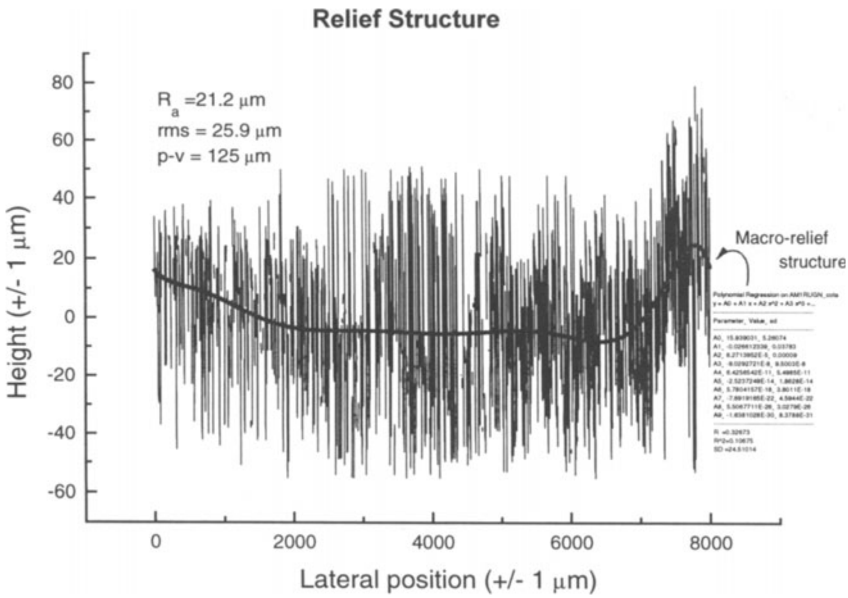


Figure 3. Profile of a typical thermoplastic rubber sole's surface before the application of the chemical product. The waviness and roughness regimes can be set apart easily ($P_a$=21.2; $P_z$=125; $P_q$=25.9; $R_q$=24.5 microns).

The values of the root mean square roughness ($R_q$) measured on the samples prior to the application of the liquid ranged between the 13.3 and 27.4 microns, with a peak-to-valley ($R_z$) roughness ranging from 94 to 150 microns. The product was then applied according to the standard rules and the topographic inspection repeated. No major differences on roughness values were noticed ($R_q$ from 13.3 to 25.7 microns) just with a minor decrease on the $R_z$ roughness (66 to 125 microns). The major difference was registered on the spatial wavelengths of the surface with a decrease of the correlation length and an increased weight of the higher frequencies of the relief structure.

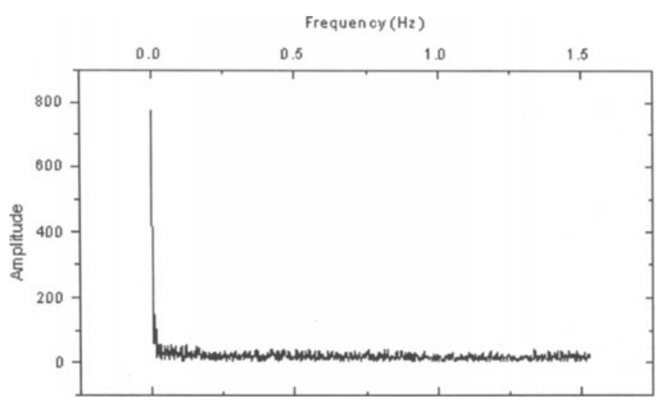


Figure 4. Fourier transform of the profile of Figure 3.

On Figure 3. is shown a typical profile of a sample before the application of the liquid. The waviness and roughness regimes are set apart. The power spectral density plot (Figure 4.) shows a Lambertian type of surface. The spatial frequency content of the same surface after application of the product is presented on Figure 5. A clear increase of the weight of the lower spatial wavelengths is noticed.

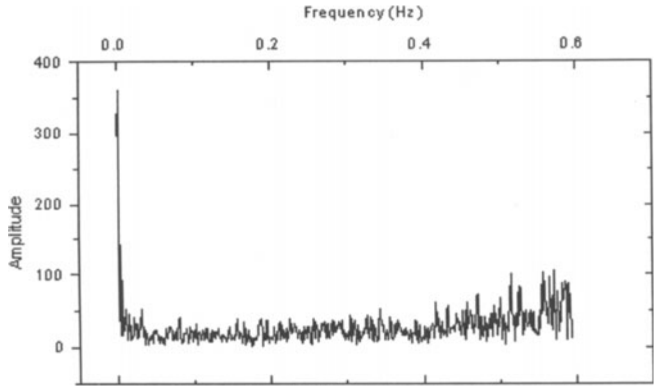


Figure 5. Spatial frequency content of the relief of the sample of Figure 3. after application of the halogenant. An increase (Figure 4.) of the content on high frequencies is clearly noticeable.

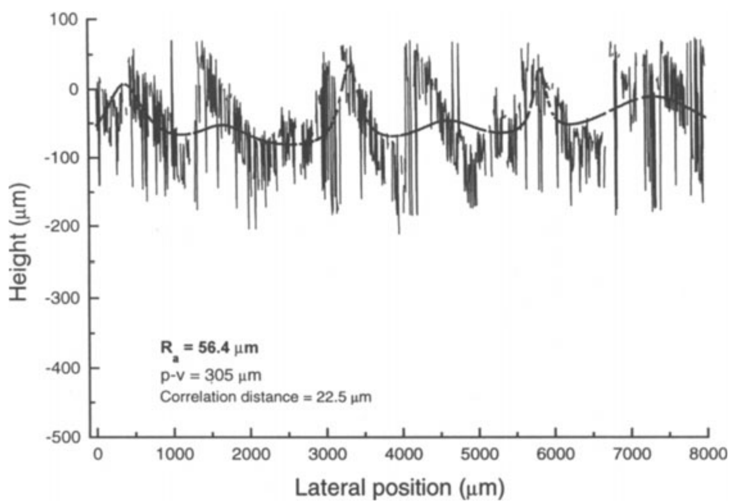


Figure 6. Profile of a very rough sample (roughness' $P_a$=56.4 and $P_z$=305 microns) obtained by pressing hardly the brush used for the application of the halogenant. The correlation length of this undulating profile is of 22.5 microns (Figure 8.).

In order to sort out any doubts we decided to use different procedures of application of the halogenant. Higher amounts of liquid, interaction time and brush's pressure were employed. Significantly different values of roughness were obtained up to 125 microns ($P_q$) and 626 microns peak to valley ($P_z$). However no increase of pasting strength was noticed. On the contrary the gluing quality decrease significantly for higher roughness.

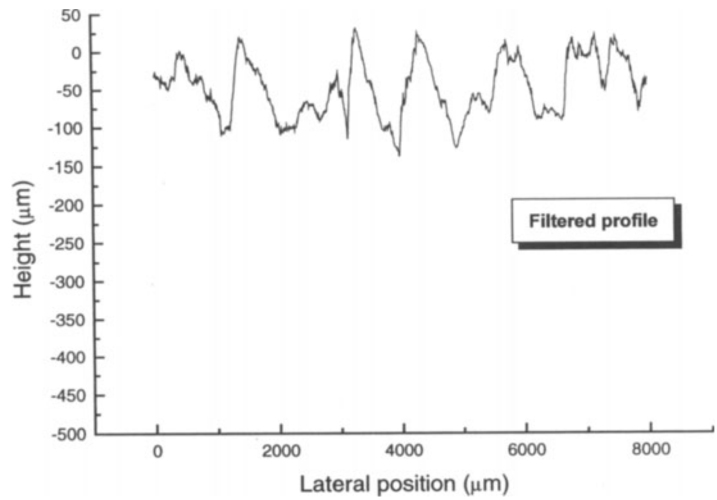


Figure 7. Waviness profile obtained by low pass filtering the profile of Figure 7.

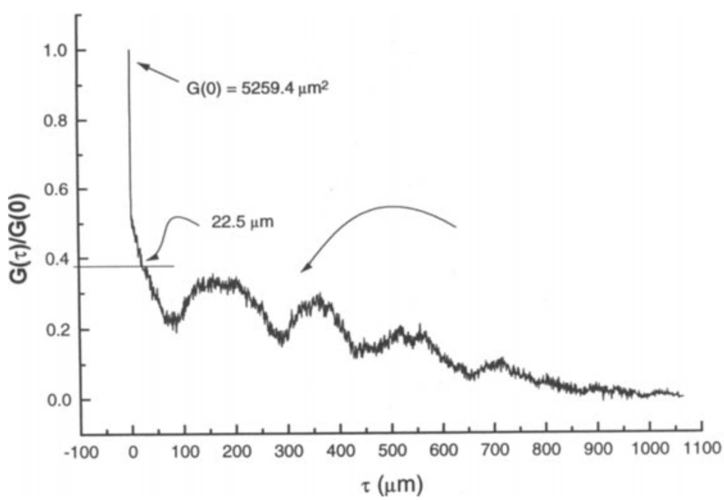


Figure 8. Autocorrelation function of the profile of Figure 7. A $P_q$ roughness of 72.5 microns and a correlation length of 22.5 microns was found.

In Figure 6. is shown the profile of one of such samples. The undulation due to the high brush's pressure applied appears clearly. The waviness profile is shown on Figure 7. The profile was again acquired with a point to point spacing of 2.5 microns. The $R_z$ roughness was found to be 67.8 microns with an understandably higher correlation length (Figure 8.).

## CONCLUSION

The application of the chemical agent on the surface of thermoplastic rubber shoe sole in order to increase the gluing strength of sole to leather, thus not change significantly the roughness of the sole's surface. Thus the interaction responsible for that strengthening should be mainly chemical.

Optical triangulation extensively proved its usefulness on the topographic and dimensional inspection of objects and surfaces of use in the industrial world[1-6]. Even with slightly translucent sample like thermoplastic rubber our triangulation microtopographer could be used with success.

## ACKNOWLEDGMENT

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